

High Frequency 2D Array Imaging

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LONG -TERM GOALS

The ability to image underwater objects in turbid water conditions is crucial to EOD divers during render safe and exploitation procedures. The beamforming, transducer, electrical interconnect, signal, and image processing technologies for high frequency acoustic underwater imaging need to be explored, characterized and developed.

OBJECTIVES

A promising method for imaging objects underwater involves using acoustically pulsed energy to interrogate mine or ordnance like targets at standoff distances. Acoustic energy is not significantly affected by visual turbidity, since the acoustic wavelengths in the MHz region are much longer than optical wavelengths. The tradeoff is that longer wavelengths reduce resolution. The objective of this effort is to develop imaging methodologies incorporating high frequency acoustics, densely packed transducer arrays, and interconnect electronics that will allow images to be created with sufficient resolution to classify mine features. In addition, image quality can be improved by developing image processing algorithms that take advantage of compound data sets and use 3D volumetric techniques such as volume rendering, template matching, and morphological filtering.

APPROACH

The principal technical issues are: the development of high density, low cost transducer arrays and their interconnects; the associated low power signal processing electronics; image processing algorithms, and compact and aperture shaded acoustic lens designs. Acoustic lens beamformers have been chosen because of the number of beams that can be formed with no power. Two different contractors have been selected to develop candidate technologies for fabrication of a transducer array with electrical interconnects that can be placed in the focal plane of an acoustic lens system. Initially, scaled down prototype units will be evaluated for downselection to a single approach. After the downselection, improvements will be made and a fully populated array will be developed for incorporation into a test bed.

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Concurrently with the transducer development, compact and shaded lens technologies are being developed to fabricate short focal length lenses that, in conjunction with the arrays under development, will form high-resolution beams with low sidelobe levels. Prototype lenses will be used in conjunction with the prototype arrays to evaluate the imaging performance of the two concepts through experimentation. The experiments will be used to validate or challenge the modeling work, which led to the designs.

The high resolution to be provided by the development of the array and lens combinations described significantly reduces the amount of image processing required to form quality images. A small image processing effort will be undertaken to determine the best method of information presentation to the diver.

WORK COMPLETED

In FY96, broad agency announcement (BAA) awards were made to QDOT and Lockheed Martin. In FY 97, QDOT delivered a 100-element prototype transducer with interconnects. Initial evaluation of the prototype has demonstrated acceptable performance of the transducer technology. The QDOT effort has been selected for Phase II.

Lockheed Martin has been able to bump bond a 16 x 16 composite array onto its readout integrated circuit (ROIC) and has conducted laboratory evaluations. The composite array demonstrated sensitivity of -188 dB re 1V/uPa at 3.1 MHz. They are currently working to bump bond the full 64 x 64 composite array to the ROIC and will then deliver the prototype system for evaluation.

The properties (absorption, sound velocity, and acoustic impedance) of potential acoustic lens materials have been established in the ultrasonic frequency ranges of interest and a final report has been generated. Lenses have been designed on the basis of the materials information gained and sample lenses have been made to validate lens designs and material behavior.

To finalize the test bed specifications prior to development, a robust, generic imaging system model has been developed that permits simulation of a variety of imaging system concepts. The modeling efforts resulted in simulation software capable of generating images of arbitrarily shaped targets for user defined system parameters. The model was developed for analysis of diver-held imaging concepts employing frequency and time multiplexing of multiple transmit/receive beams.

In parallel with the modeling work, the retina transducer array backing, interconnection structure, and signal processor chip packaging were completely redesigned in FY98 to form a more compact, single plug-in, replaceable unit. Transducer tiles were resized down to a 1.4-mm pitch, and three new filler materials were generated and tested. Disposable matching layer masks were designed, procured, and tested successfully. The row-by-row flex circuit interconnect technique was replaced by a backing block with a plated via mass interconnect methodology. The signal processor chip was reconfigured to implement a simpler detection algorithm.

RESULTS

The most important results of FY98 can be broken into four areas. First the results of the modeling have shown that a robust computer model provides a powerful analysis tool capable of modeling a variety of imaging systems. Diver-held image system modeling has shown that a reduction in receiver processing channels by a factor of nine may be achieved using three transmit frequencies and three transmit cycles to generate an image. Modeling also showed that the required frequency filtering to separate adjacent channels does not place unrealistic requirements on the electronics design. Modeling also demonstrated the advantages of monostatic mode of operation where each separate beam is used for transmission and reception compared to bistatic operation where a separate projector array is used to broadly insonify the target. The effects of sidelobes on image quality was shown to be significant as it was demonstrated that sidelobes must be reduced to low levels (less than -30dB) for acceptable images to be achieved.

Secondly, the image processing research study documented conclusions about each of the following factors that directly impacted the phase two-test bed design.

Data Visualization. Viewing the full volume data at such high frame rates presents a challenge. Extracting the target surface and viewing it as a 2D-range image, or as a surface rendered 3D "relief image" appears to be the best solution.

Surface Extraction. First maximum return above a threshold (along each beam) yields satisfactory images. The user can find the best threshold by adjusting a "knob." A median filtering (3x3) of the extracted surface generally appears to be useful for overcoming a sub-optimal threshold and for noise removal.

Intensity Images. The alternatives are "intensity at the detected range" (intensity image) and "intensities integrated along beam" (acoustic photo). Neither one is as informative as the range image. The acoustic photo is typically more useful than the intensity image. Either one may complement the range image.

Dynamic Range. The typical dynamic range in the simulations is about 30 dB. However, even a dynamic range of 20 dB (or lower) leads to no noticeable degradation of images, provided that only the high returns are saturated while low returns remain intact. Also, a threshold sensitivity of 2 dB is desirable, but 3~dB may be adequate.

Monostatic vs. Bistatic Imaging. Monostatic imaging yields superior images. Bistatic imaging provides adequate images of larger features. In real images, however, when noise is present features are going to be further smeared. This degradation may render bistatic imaging inadequate for our purposes.

Time-Frequency Multiplexing (3 vs. 6). Six-frequency (at six times) imaging yields better results than imaging with three frequencies (at three times). However, with the application of median filtering, 3- and 6-freq images appear to be comparable.

Sampling Rate. No significant degradation can be observed by going from a sampling rate (along range) of 1/8 cm to 1 cm.

Pulse Length. No significant differences are observed by changing the pulse lengths from 0.5 cm to 2 cm.

Shading. Aperture shading noticeably improves image quality.

Reflections. Internal reflections in the lens do not appear to significantly degrade image quality.

The third area of significant results was in development and testing of less expensive manufacturing and assembly techniques. We are currently developing transducer tiles on a smaller, 1.4-mm pitch using a newly developed filler material. These new assembly techniques include a more reproducible and reliable matching layer application technique using disposable masks; a far cheaper backing mass interconnection assembly methodology; and a rigid, attenuative backing structure for mass interconnect to integrated circuit chip-scale packaging. Tests demonstrated 97% hot electrode interconnection using FR4 printed circuit board (PCB) material. Insufficient acoustic attenuation within the FR4 backing block was also demonstrated. The plated through hole process was successfully applied to urethane filler materials. Primary results from this work include:

1. The demonstration of the viability of mass interconnect from the acoustic tile to the backing.
2. The viability of using standard PCB plated-through via processes on polyurethane filler and potential backing materials.
3. The need for a backing more attenuative than standard PCB materials, even with higher loss tile filler materials.

The preliminary design of the chip-scale package demonstrated the feasibility of the concept of combining the transducer array, backing, and signal processor into a single plug-in unit. The signal processor chip was simplified and changed to switched-capacitor technology instead of the original charge coupled device technology. This will reduce both the unit cost and the program risk.

The fourth area of significant results was in the improvement of the transducer hybrid array fabrication process in the Lockheed Martin effort. Interconnect fabrication and hybridization of 1-3 composite transducer arrays to ROICs is straightforward for 16 x 16 arrays that have dimensions of approximately 0.25 x 0.25 inches per side. These arrays have exhibited excellent reliability and consistency of test results. The larger 32 x 32 and 64 x 64 arrays which have linear dimensions of 0.5 and 1.0 inches, respectively, also give good results but are not able to maintain bump contact for more than 24 to 48 operating hours. The failure mode is bump failure where the indium metallization fails in tension. A new bump metallurgy, an indium tin alloy, and a process for deposition which maintains stoichiometry is being optimized on the Sonoelectronics program. It will be applied to arrays later this fall.

IMPACT/APPLICATIONS

We continue to develop the technology building blocks through improvement of integrated transducer and electronics fabrication processes, development of advanced models and increasing our knowledge of complex lens systems. As these efforts mature, the development of a portable high-resolution hand-held imager will become realizable. The new capability for EOD divers will be unsurpassed underwater acoustic vision in a diver-held package.

TRANSITIONS

The 2D-array technology developed under this program is expected to transition to an advanced development effort funded by PMS-EOD. Potential for transfer to a 6.3 core effort exists and other sources will be sought out as well.

RELATED PROJECTS

The Australian Defense Science and Technology Organization has an ongoing program in electronically beamformed underwater imaging at similar frequencies for use on remotely operated vehicles platforms. The possibility of using the sparse array technology for diver applications is being investigated as well.

The Defense Advanced Research Projects Agency has initiated an underwater acoustic imaging program focusing on microelectromechanical systems. The Lockheed Martin phase one effort has transitioned to this program.

REFERENCES

Folds, Johnson, Kamgar-Parsi, 1997: "Diver-Held Imaging System Modeling," Proceedings from the 23rd International Symposium on Acoustical Imaging, 13-16 Apr 97, Boston, MA.